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SIMULATING THE EFFECTS OF THE LAST HUNDRED YEARS OF FIRE MANAGEMENT AND RAINFALL VARIABILITY IN NORTH AUSTRALIA.

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ABSTRACT

We present the new FLAMES computer simulation model of vegetation dynamics in north Australia and use it to examine the impacts of various fire regimes and historical rainfall patterns on tree density in a north Australian savanna. We show that frequent late dry season fires can greatly reduce tree densities, but only if they are fronting rather than point sourced fires. Our model assumes idealised patterns of fire spread under these two scenarios, but the actual spatial variation in fire spread is poorly documented in north Australia. The pattern of fire spread is shown to be a crucial issue in understanding woody vegetation dynamics and needs further research if the impacts of management are to be reliably simulated.

INTRODUCTION

Understanding tree dynamics is critical to management of pastoral productivity, biodiversity and carbon storage in the savannas of North Australia. Tree density varies systematically with soil type and rainfall (Williams et al 1996) but can be reduced quickly by droughts and intense fires (Fensham and Holman 1999, Williams et al. 1998). Because grass production is often inversely proportional to tree density (Scanlon and Burrows 1990), many pastoral land managers are interested in maintaining tree density as low as possible. Nevertheless, their land management practices often lead to increased tree densities through fire exclusion and increased grazing pressure on savanna grasses (Archer and Stokes 2000).

Unlike most of Australia, in which fires have been excluded or very tightly controlled since European settlement, the Top End of the Northern Territory, has retained frequent burning as a dominant management practice (Russell-Smith et al. 1997). The major issues in fire management are the season of burning (early dry season or pre mid-July versus late dry season or post mid-July) and the frequency of burning. Early fires tend to be of lower intensity than late fires. Ignition style is also an important factor in determining the severity of fire regimes. Many land managers who use fire aim to burn country quickly and light line fires either from the ground or using incendiaries. If lit perpendicular to the main wind direction, these fires will spread at the maximum rate for the given conditions. Most country will then receive the maximum possible fire intensity. In contrast point-sourced fires typically spread in an ellipse, in which a large proportion of country is burnt with relatively slow-moving flanking fires which burn with a low intensity.

We have developed a computer simulation model, FLAMES, that allows the effects of climate variability and fire management on the growth of trees and grasses to be simulated for different soils types across northern Australia. Although fire histories are being developed for the past few decades from satellite imagery, more historical data are lacking, and there is little information on intensities, so simulation modelling provides a valuable tool to examine possible scenarios. In this paper, we use the model to investigate the effects of historical rainfall patterns and different fire management regimes on tree density in northern Australia.

METHODS

The FLAMES simulation model for savannas determines grass production and tree density by taking account of daily soil water dynamics and the impact of fire and grazing animal management. It has been satisfactorily evaluated against field data in preliminary studies. We parameterised the model for the four dominant trees species and dominant soil type at Kapalga, Northern Territory. Using daily rainfall records from 1911 until 1999, we simulated the impacts of different fire regimes on a starting population of trees that was typical for the region. The regimes varied according to their timing (early: June morning or late: September afternoon), frequency (1 in 5 years to annual) and ignition style (fronting or point sourced). For each scenario, we performed the simulation four times and calculated mean values.

RESULTS

Mean fire intensities were greatest for late dry season fronting fires, and these intensities decreased with increasing fire frequency (Figure 1). Fronting fires early in the dry season had mean intensities similar to those of point sourced in the late dry season. These fire intensities also decreased with increasing fire frequency. Fire intensities were least for early dry season point sourced fires and these decreased very slightly with increasing fire frequency.

Late dry season fronting fires produced the most extreme effect on tree basal areas (Figure 2). Frequencies of two years in five or more reduced basal area by more than one third that in the absence of fires. There was relatively little difference amongst the other fire regimes in their effects on tree basal areas. Increasing severity of fire regime caused a decline in the relative proportion of large trees (> 40 cm) and an increase in the proportion of medium sized trees (20 cm to 40 cm) (Figure 3).

The effects of the late fronting fires were immediately apparent upon instigation of this regime, but late dry season point-sourced fires only showed a substantial effects after many decades. This is demonstrated in Figure 4 for fires with a frequency of two in five years, which is typical of the region (Russell-Smith et al. 1997). The percentage of days in which the soil profile was at wilting point was greatest in the absence of fire and decreased with increasing fire frequency. The magnitude of this decrease was greatest for late fronting fires (Figure 5).

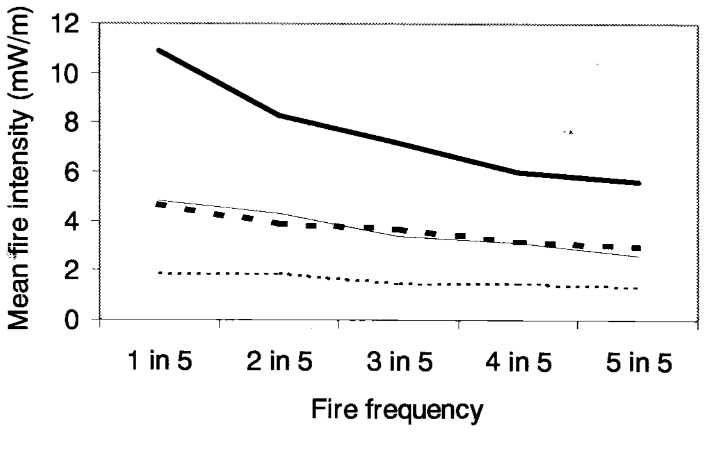

Figure 1. The effect of fire frequency on mean fire intensity for idealised fronting and point sourced fires early (thick dashed and thin dashed lines respectively) and late (thick solid and thin solid lines respectively) in the dry season at Kapalga, NT.

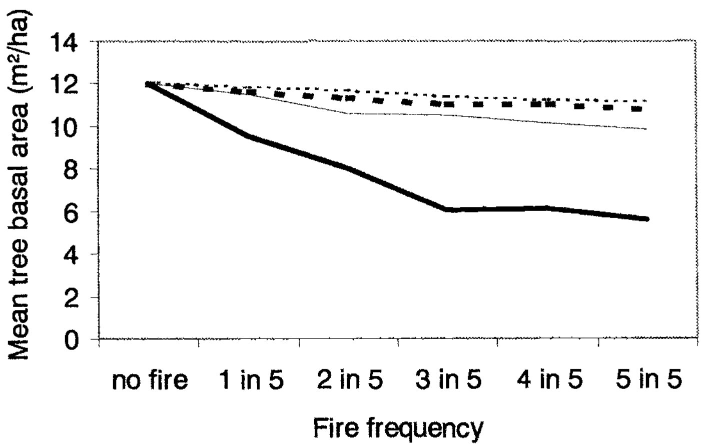

Figure 2. The effect of fire regime on mean tree basal area (see Figure 1 for legend).

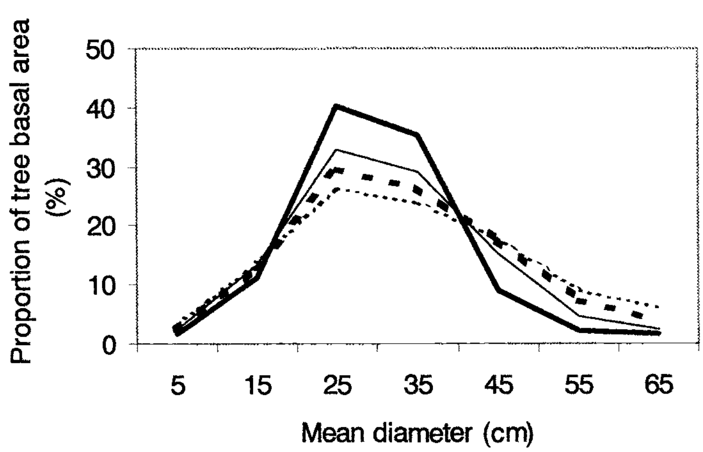

Figure 3. The effect of ignition style and fire seasonality on the proportion of trees in particular size classes across all fire frequencies (see Figure 1 for legend).(see Figure 1 for legend).

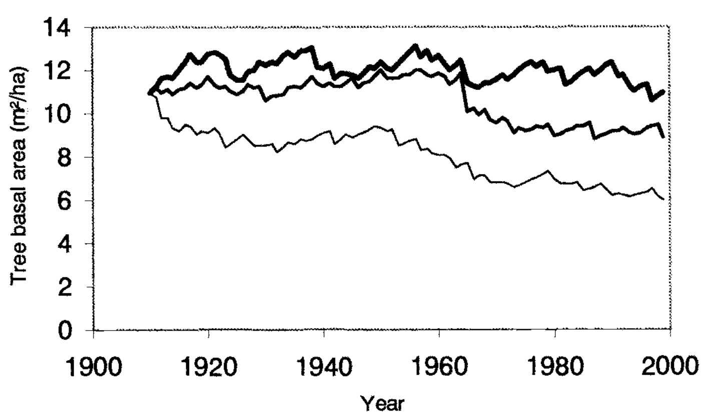

Figure 4. Changes in mean total tree basal area over time under no fires (thick line) and fires with a frequency of two year in five. (late dry season point-sourced fires: medium line; and late dry season fronting fires: thin line).

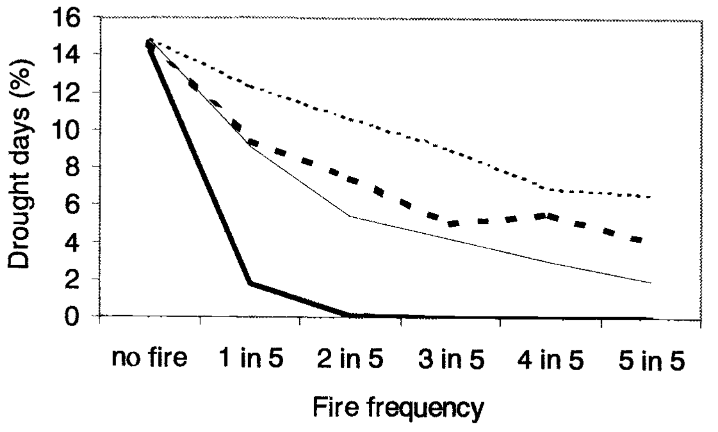

Figure 5. The effect of fire regime on the mean proportion of days in which the soil profile is at wilting point (see Figure 1 for legend).

DISCUSSION

Trees in the high rainfall savannas of the Northern Territory are noted for their high resilience to fire. Nevertheless, our simulations indicate that frequent fronting fires late in the dry season can greatly reduce tree density and particularly the density of large trees. The impacts of fires can be reduced by decreasing their frequency, despite the impact that this has on mean fire intensity. The impacts can also be reduced by burning earlier in the dry season or by changing to point sourced ignitions. Fires lit by managers of pastoral lands or conservation lands tend to be fronting fires whether lit from the ground or from the air. These fires result in most country being burnt at the maximum rate of spread for the given conditions. In contrast, point sourced fires such as might be lit by lightning strikes or by traditional land managers spread at a range of rates in different directions, with a relatively high proportion of country being burnt by relatively slow moving flanking fires. In the FLAMES model, this is represented by an idealised ellipse. In practice, given the spatial heterogeneity in landscapes, and temporal variations in weather conditions, patterns of fire spread will be somewhere between these two ideal models of fire spread. Better understanding real-world patterns of fire spread is therefore a critical issue in predicting the impact of different fire management options.

Large scale dieback of trees due to drought have been noted in Queensland for over a century, with the most recent event being in central Queensland in the early 1990s (Fensham and Holman 1999). However in the Top End of the Northern Territory, such dieback events have not been recorded. Nevertheless, an analysis of rainfall records for Oenpelli indicates that there have been 7 major periods of extended drought since records started in 1911 (Clewett et al. 1999). Our simulations of vegetation dynamics and soil water balance show that the likelihood of tree water deficit increased with decreasing severity of the fire regime. Under existing fire regimes, droughts rarely result in trees suffering water deficit because tree density is limited by fire regimes rather than water availability.

Until FLAMES was developed, there was no satisfactory model to simulate the impacts of land management and the physical environment on trees in north Australia. In other studies, we have shown that FLAMES successfully reproduces field observations of water use and fire impacts in the Top End of the Northern Territory. We believe that further development of this model and its application to various case studies across north Australia will contribute greatly to our understanding of the effects of land management and climatic variation on tree populations, water balance, grass production and carbon storage in this region.

ACKNOWLEDGEMENTS

We thank John Ludwig for helpful comments on this manuscript.

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